Revista Ciencias Técnicas Agropecuarias, Vol. 32, No. 3, july-september 2023, E-ISSN: 2071-0054

REVIEW

GIS Tools, Review of their Foundations, Types and Relationship with Spatial Databases

Herramientas SIG, revisión de sus fundamentos, tipos y relación con las bases de datos espaciales

https://cu-id.com/2177/v32n3e10

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ABSTRACT: Geographic information systems offer an environment capable of integrating, storing, editing, analyzing, sharing and displaying geographically referenced information. They are tools that allow users to create interactive queries, analyze spatial information, edit data, maps, present the results of all these operations. This article describes the basic concepts of these systems. Likewise, the forms of data representation are shown, as well as the use of the main current spatial database software. Several works that establish comparisons between the main geographic information systems of the market are analyzed. Finally, the use of geographic information systems in agriculture is addressed.

Keywords: Geographic information system, spatial database, representation of spatial data, GIS development tool.

RESUMEN: Los sistemas de información geográfica ofrecen un entorno capaz de integrar, almacenar, editar, analizar, compartir y mostrar la información geográficamente referenciada. Son herramientas que permiten a los usuarios crear consultas interactivas, analizar la información espacial, editar datos, mapas, presentar los resultados de todas estas operaciones. En este artículo se describen los conceptos básicos de estos sistemas. Asimismo, se muestran las formas de representación de los datos, así como el uso de los principales softwares de bases de datos espaciales actuales. Se analizan varios trabajos que establecen comparaciones entre los principales sistemas de información geográficas del mercado. Por último, se aborda el uso de los sistemas de información geográfica en la agricultura.

Palabras clave: Sistema de información geográfica, base de datos espacial, representación de datos espaciales, herramienta de desarrollo SIG.

INTRODUCTION

Since the end of the 20th century, Information Technology has become one of the most important tools in the development of society. The growing development of Information and Communication Technologies and positioning services has enhanced the availability of geographic information for various sectors of the society. This, in turn, has led to the creation of Geographic Information Systems (GIS) as tools capable of processing the large amount of existing data and providing new information (Pérez-García, 2019). The emergence of this technology has served as a benchmark for technological development in different areas such as agriculture, livestock, hydrography, tourism, topography. (Barrera-Narváez *et al.*, 2020).

GIS are information systems made up of hardware, software, and procedures to capture, manage, manipulate, analyze, model and represent georeferenced data, with the aim of solving problems of management and planning (Goodchild & Kemp, 1990). They are a framework for collecting, managing and analyzing data. Rooted in the geography branch, it integrates many types of data. Analyze spatial location and layer information into visualizations using maps and 3D scenes. With this unique ability, GIS reveals deeper insights from data, such as patterns, relationships and situations, helping users make smarter decisions.

In the 20th century, specifically in the year 1962, Roger Tomlinson created the first GIS in Canada, which is why he is considered the father of GIS and it is based on that study that the Institute appeared that same year. Systems Research Institute - Environmental Systems Research Institute (ESRI), which currently develops applications for GIS. At present, the progress of GIS has been dizzying, especially with the use of the Internet as a massive platform for communication and management of geographic data (Pérez-Garcia, 2019).

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Received: 16/11/2022

Accepted: 24/06/2023

GIS has become a powerful, time-efficient and cost-effective technique for geologists, scientists, and engineers who have previously been solving problems related to geospatial data in traditional ways (using printed maps). Today, GIS offers professionals the ability to create their own digital maps and represent information about the real world in a visual way that easily reveals patterns, trends and relationships about anything that has a geospatial context. They have become a powerful tool for data capture, data sharing, communication and collaborations (Zhou, 2021).

Any science related to space, especially geography, analyzes the territory through different thematic layers (soil and its uses, municipal areas, the hydrographic network, the settlement system, road infrastructures -- roads, railways. ..-- the distribution of equipment and services...). That is, detecting and using, isolated or jointly, different layers of information from the same area. In this way, the researcher can analyze each of these thematic layers depending on the objectives of his study. In this sense, the great advantage of GIS is that they can relate the different layers to each other, which gives these systems excellent analysis capabilities, allowing them to respond to complex requests and, therefore, produce derived maps that can represent real situations or very useful hypothetical or simulated scenarios (López-Lara *et al.*, 1998).

In this article the basic concepts of these systems are presented, the forms of data representation are shown, as well as the use of the main current spatial database software. Several works that establish comparisons between the main geographic information systems on the market are analyzed. Finally, the use of geographic information systems in agriculture is addressed.

DEVELOPMENT OF THE TOPIC

Basic concepts

When talking about the characteristics and functionalities of GIS, it is important to be clear in advance about some basic concepts about the characteristics of the information that they manipulate. Geographic type information can be classified into two categories, depending on whether it represents characteristics of the geographic space (attributes referring to the geographic space) or, on the contrary, it represents properties of the managed objects (attributes referring to the objects).

Basic Concepts Related to Geographic Space

Geographic space is defined as the coordinate space (usually R2) in which geographic data are represented, which is usually either Cartesian (in case the GIS uses a flat world model) or geodetic. About this geographic space, certain information can be stored, consisting of alphanumeric attributes of which a value of its domain is associated with each point in space (Brisaboa *et al.*, 2000).

Other authors such as Santos (1998) define it as an inseparable set in which, on the one hand, a certain combination of geographical objects, natural objects and social objects participate, and on the other, the life that fills and animates it, that is, society in motion. The content (society) is not independent of the form (geographical objects), and each form contains a fraction of content. Space, therefore, is a set of forms, each of which contains fractions of society in motion.

This information that is stored about the geographic space is called geographic space attributes (hereinafter AEG). An AEG can be continuous (if the value associated to the space points can vary gradually throughout the geographic space) or discrete (if the set of values that the attribute associated with the geographic space can take is discrete). An example of a discrete AEG is crop type, while an example of a continuous attribute would be soil salinity, temperature, or atmospheric pressure.

Basic Concepts Related to Objects

According to Brisaboa *et al.* (2000) on the geographic space, the geographic objects are represented, which are objects that the GIS must handle and represent graphically. This is how they are:

Object or Geographic Entity. It is an object on which the GIS application saves not only alphanumeric information but also geographic information that allows it to be represented graphically on a map. For example, if we consider the geographical object "Town of San José de Las Lajas", in addition to alphanumeric attributes such as "name", "population", etc. may have a geographic attribute "Location of the UDP* El Guayabal" that represents the position of the UDP El Guayabal and another geographic attribute "area" that represents the area of geographic space occupied by it. At the time of visualization, the GIS can, for example, use the attribute "Location of the UDP El Guayabal" to represent the city in presentations at a scale of 1:25,000 or less and use the attribute "area" to represent the city in presentations at larger scales, where this information may be more useful. It is convenient not to confuse here the (display) scale with the precision of the representation of the geographic attributes, which is the resolution with which the geographic information is stored in the GIS.

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Geographic Attribute. It is an attribute that represents information referring to a geographic characteristic of the object to which it belongs (position, extent, etc.). It is a non-empty and possibly infinite subset of geographic space. Geographic attributes are represented by geographic figures and their type corresponds to the type of geographic figure that is used to represent it.

Geographic Figure. They are used to graphically represent geographic attributes of an object on the plan. Various types of geographical figures are used in the domain of GIS; the most common are the following:

- Point: The value of a geographic figure of this type corresponds to an element (point) of geographic space. An example of a geographic attribute representable by such a geographic figure is the position of an object, such as the geographic location of a post office.
- Line: A geographic figure of this type corresponds to a set of curves in geographic space, where a curve is a sequence of contiguous points in space. An example of geographic attributes that can be represented by a line is the course of a river or the layout of a road.
- Region: The value of a geographic figure of this type corresponds to a set of areas of geographic space. Examples of geographic attributes that can be represented by a region are the area of space occupied by a parcel of land or the area of a country affected by snowfall on a given day.
- Geographic: The value of a geographic figure of this type corresponds to a set of points and/or lines and/or regions of geographic space. Although less used than the previous ones, this type of geographic figure is also useful in certain application domains to represent geographic attributes.
- Partition: A geographic figure of this type represents an element of a partition of geographic space into disjoint areas. An example of a partition-type geographic attribute is the area of a school in a province, in which the municipalities cannot overlap and the area occupied by the set of all its municipalities must exactly coincide with the entire area of the province.

An example of the above can be seen in Figure 1 where the geographic attributes corresponding to various geographic objects at two different scales can be seen, as well as the representation of two attributes of geographic space. More specifically, it is observed how to scale. E1 the geographic object "c" (representing a city) is represented by its geographic attribute "Location of a School", of point type, while the geographic object "r" is represented by a

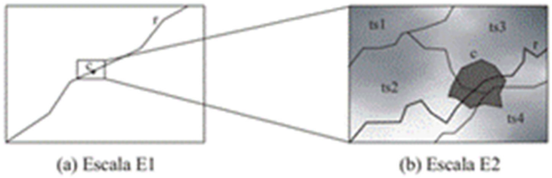

FIGURE 1. Example of geographic objects at different scales. Source: (Brisaboa *et al.*, 2000).

geographic attribute of line type. At the E2 scale, the object "c" starts to be represented by its geographic attribute "area", of region type, while "r" continues to be represented by the same attribute of line type (although by using a larger scale in the presentation it can be viewed in more detail). At this E2 scale, the discrete geographic space attribute (AEG) "soil type" can also be seen, which divides the space into four regions with values ts1, ts2, ts3 and ts4, respectively, and the continuous AEG "salinity" (colors plus the dark ones represent lower soil salinity values.) In the case of Figure 2, something similar can be seen, a point-type geographic object that represents a property and as the scale increases, the object becomes a point to an area. In this figure, a new type of map on a satellite image can be seen.

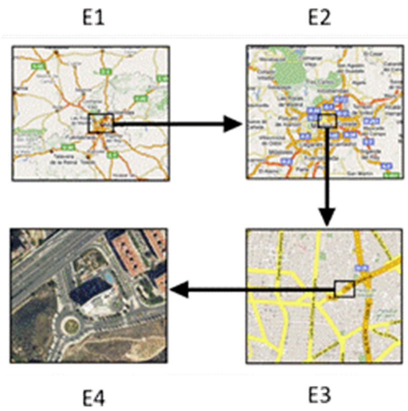

FIGURE 2. Example of geographic objects at different scales and types. Source: self made.

In GIS software, geographic features that have the same geometric and attribute representation are often grouped into so-called "layers" to simplify data management tasks. For example, all buildings that are represented by polygons and have information about the owner and the year of construction are grouped in a "buildings" layer (Steiniger *et al.*, 2010a).

A GIS can be made up of several data layers that allow complementing the terrain map. These layers contain the coordinates of the area they occupy and allow more data to be added for information sampling and decision making. Figure 3 shows the extrapolation of several data layers on a map; in this case, data for streets, buildings and vegetation are represented.

When carrying out analysis, the more information about the terrain is obtained, the more accurate the result will be.

Data Representation in a GIS

The representation of spatial data (which represents the locations in a database) can be done in two basic formats: i) Vector format and ii) Raster format. The vector format is represented as points, lines, and areas, and the raster format is represented as a grid of cells/pixels. The vector format is based on views of discrete objects of reality (analog maps) and the raster format is based on a network made up of cells or grids (photographs, images, etc.), in which each grid (pixel) presents a quality or spatial property (color, altitude, among others). The main difference with respect to a vector file is that pixels are stored in the raster file while in the vector file the coordinates of the vertices of each geometric element are stored.

In principle, any situation in the real world can be represented digitally in both raster and vector formats. Raster-based GIS represent data with points (bits) on a map (Figure 4). The locations are represented in a grid of cells. In the figure, the surface of a lake is mapped to a GIS raster, resulting in the blue group of cells on the right. The cells do not exactly match the contours of the lake. The "squaring" of the edges is called aliasing and is caused by imperfect sampling of smooth curves. Taking more samples (i.e. using smaller grids with more bits per unit area) results in less aliasing and a better representation of physical reality. This is called higher resolution and is a term used throughout the space technology domain to measure error. Better resolution means fewer errors, but is more expensive to acquire. The accuracy of GIS maps depends on how many data samples are taken per unit area. Vector-based GIS represent physical features in nature as points, lines or polygons (Figure 5). It should be noted that there is also overlap in vector GIS. In this case, the curvilinear boundaries of features such as lakes or roads are measured with straight line pieces. The more small lines that are used, the better the true nature of the function will be captured (Macarthur, 2002).

In their works Matellanes-Ferreras (2017) and GEOINFORMATION (2020) establish a comparison between raster and vector data according to several significant aspects, where the main differences between the two can be appreciated. Table 1 shows a summary of this comparison:

GIS and Spatial Databases (BDE)

GIS data are stored in spatial databases, allowing users to manipulate information in relation to other information seamlessly. Objects from the real world (roads, land use, altitudes) can be represented grouped into two abstractions: discrete objects (a house) and continuous objects (amount of rainfall, an elevation) (Boria *et al.*, 2020).

BDEs are an integral part of GIS by providing capabilities to represent, store and access data, in addition to solving the problems of concurrency control, transaction management, backup and failover (Vitturini *et al.*, 2003). They allow the storage of the geometries of a cartographic file in a database.

BDEs offer capabilities for the proper handling of spatial data, including models for the representation of spatial objects, fast retrieval methods and specific query languages. Spatial data are made up of spatial objects constructed from points, lines, regions, rectangles, surfaces, volumes and even higher-dimensional objects that may include temporal constraints. Examples of spatial data include cities, rivers, routes, mountainous areas, among others (Vitturini *et al.*, 2003).

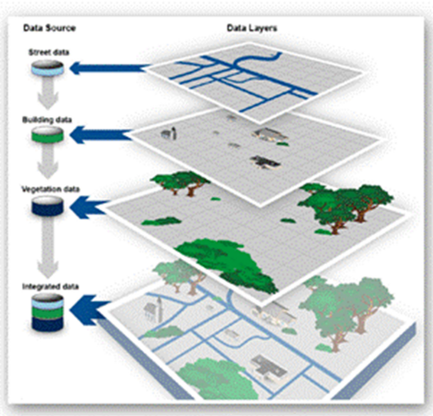

FIGURE 3. Visual representation of various data layers in a GIS. Source: Zhou (2021).

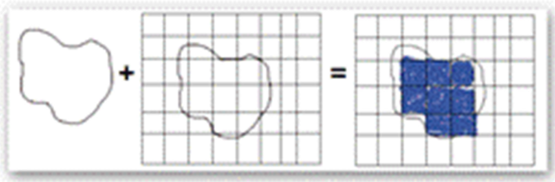

FIGURE 4. Representation using the Raster model of a lake. Source: Macarthur (2002)

FIGURE 5. Representation using the Vector model of a lake. Source: Macarthur (2002).

TABLE 1. Comparison between the raster data structure and the vector data structure. Sources: Matellanes-Ferreras (2017) and GEOINFORMATION (2020)

Features	Raster data	Vector data
Introduction	A type of spatial data that is made up of a square grid of pixels.	A spatial data type that consists of points and polygons.
Nature of the data	Continuous data	Discrete data
Representation	Data is represented in cells or pixels.	Represents data using lines, points and polygons.
Data structure	It is a simple and low cost data structure.	It is a complex and expensive data structure.
Location identifier	The raster data model uses a series of cells or pixels to represent locations on the earth.	The vector data model uses point and line segments to identify locations on the earth.
Overlap operations	In raster data overlay operations, the operations are easily implemented.	On vector data overlay operations are difficult to implement.
Example	Temperature, rain and elevation.	Administrative boundaries and linear entities such as roads and rivers.
Ability to compact information	It is not possible to compact the information	The information is compacted using a smaller volume of data.
Precision	The level of precision is given by the size of the cells, but there is always a margin of error in the calculations of surfaces and distances.	Greater precision for calculating surfaces and distances.
Limits	Limits based on the pixel size itself and have certain difficulties to develop spatial analysis.	More precise limits as they are lines and points that are easy to define and distribute.
Structure	Simple and basic model, but not very compact and it has quite a few difficulties to represent information when there are very large files	Simple but compact model. The representation of the information is simple and greatly facilitates the level of precision.
Three-dimensional representation	They can represent reality by using three-dimensional arrays.	They have a flat character and are not able to be represented in the same way in space.
Commercial use	Difficult to generate and obtain, so they present a higher economic cost.	They are more used and shared because of their ease of generation.
Assignment of qualitative or quantitative attributes	They better support the incorporation of data from the beginning of the creation of the file when it comes to satellite images. But it is difficult to edit the data later.	Ease of editing data.
Generation of rules and topological conditions	Less easy when developing topological rules and conditions	They generate topology problems (overlaps between elements of the same layer).

On the other hand Hamid *et al.* (2020), affirm that the main component of a GIS is its information database. This database is sophisticated by taking information from various sources such as topographic maps, thematic maps and cadastral maps, equivalently, remotely detected images in digital form, among others. Whatever the basis of the information is, it is essential to combine them in a common projection and recording.

There are several BDE alternatives that make it possible to store and process georeferenced information. Table 2 shows a summary of some software.

Choosing the right spatial database is extremely important. Each system has its own advantages and disadvantages that depend on the type of data ingested and the expected result of the analysis. Making the right decision becomes increasingly difficult as BDEs add spatial modules or extensions for use with geospatial data (Deprizio, 2020).

In their work, Agarwal & Rajan (2016) make a comparison between PostreSQL (PostGIS) and MongoDB where the advantages and disadvantages of using a spatial database system using relational and non-relational databases are analyzed. The authors reflect in this document the utility of PostgreSQL as one of the best open source alternatives for spatial data storage.

They also conclude that MongoDB performs better as data size increases in indexed and non-indexed operations for both the line intersection and the point contention problem; NoSQL databases may be better defined for multi-user simultaneous query systems, including Web-GIS and mobile-GIS; non-relational databases are better suited for multi-user query systems and have the potential to be deployed on servers with limited computing power.

On the other hand, they state that there are still some limitations in the use of NoSQL databases over SQL databases. There aren't as many spatial functions in NoSQL as there are in SQL. Currently implemented

*No usan SQL como lenguaje de consultas. Los datos almacenados no requieren estructuras como tablas, utiliza un esquema similar a JSON.

TABLE 2. Alternatives of spatial databases. Source: self-made

Name	*Description*	*Developer*	*Release date*
MySQL Spatial	MySQL extension, default database on hosting platforms and, therefore, widely used by web developers.	Oracle Corporation	1995
Spatialite	SQLite extension, very simple file-based database.	Alessandro Furieri	2008
PostGIS	PostgreSQL extension, powerful cross-platform database that is fully compliant with the standards offered by the Open Geospatial Consortium (OGC).	Refractions Research	1996
H2GIS	Extension of H2, a lightweight database programmed in Java, which works via files in the same way as SQLite.	Thomas Mueller	2005
GeoTable	Cloud-based spatiotemporal database built on top of Apache Accumulo and Apache Hadoop (also supports Apache HBase, Google Bigtable, Apache Cassandra, and Apache Kafka). GeoMesa supports full OGC simple functions and a GeoServer plugin.	LocationTech, CCRi	2015
Oracle Spatial and Graph	A free component of Oracle Database, it provides spatial features for managing geographic and location data with native data types.	Oracle Corporation	2011
MongoDB	NoSQL Database System*. Instead of storing data in tables, as is done in relational databases, MongoDB stores BSON data structures (a specification similar to JSON).	MongoDB Inc.	2009
MarkLogic	NoSQL enterprise database, is considered a multi-model NoSQL database for its ability to store, manage and search JSON, XML and data semantics (triple RDF) documents.	MarkLogic Inc.	2001
neo4j	Graph-oriented database, implemented in Java. Fully transactional, disk-based, embedded persistence engine that stores structured data in graphs instead of tables.	Neo4j	2007

geographic functions only support very basic operations. Relational databases are still far superior if the user needs to compute geographic information at the database level.

In his article Deprizio (2020) presents a comparison of the main BDEs currently most used. MySQL, MongoDB, MarkLogic, Neo4j and PostgreSQL (using PostGIS) are discussed. The research analyzes the processing of a set of spatial operations in each of these BDEs. PostgreSQL stands out for data insertion, while MarkLogic is the fastest for querying.

PostgreSQL and its PostGIS extension are, in both cases, a common denominator among the BDEs analyzed. Among the most relevant characteristics, according to Agarwal & Rajan (2016) are:

- Supports geometry types for Points, LineStrings, Polygons, MultiPoints, MultiLineStrings, MultipPolygons and GeometryCollections.
- Supports spatial operators to determine geospatial measures such as area, distance, length and perimeter.
- PostGIS also supports R-tree-over-GiST (Generalized Search Tree) spatial indexes for high-speed spatial queries.
- The PostGIS implementation is based on "lightweight" geometries and indexes optimized to reduce disk and memory footprint.

GIS Development Tools

There are several companies and organizations that develop new GIS tools. Steiniger *et al*. (2010) classify them according to their functionality into seven types: (i) Desktop GIS, (ii) Spatial Database Management System (SDBMS), (iii) Web Map Server, (iv) GIS Server, (v) GIS web client, (vi) mobile GIS and (vii) Libraries and extensions (Figure 6).

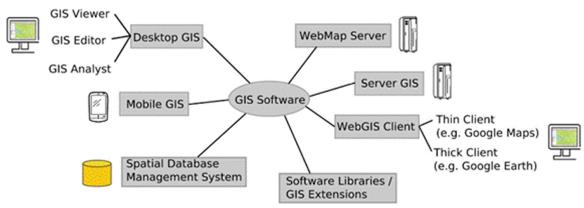

FIGURE 6. Different types of GIS software. Source Steiniger *et al*. (2010).

In Steiniger & Hunter (2013) each of these types of GIS and their functionalities are defined. They explain that the selection process, whether for companies, research or teaching, must be based on a rigorous software evaluation process. They maintain that among the criteria that must be applied during the evaluation of the process are, for example: software functionality, software stability, platform support, market share, credibility (brand) of the software manufacturer, as well as the size of the support and distribution network. While these criteria are common to the selection of proprietary software, with respect to free and open source software, other criteria are also important. In particular, the project that created the software should be considered, as the status of the project will influence the support, evolution (in terms

TABLE 3. Final result of the GIS comparison of commercial and free licences. Source: Olivo-Bermeo (2019)

	Weight	QGIS	GvSIG	ArcGIS	Global Mapper
Functionality	11	9	8.5	11	10
Spatial Analysis	4	3	1	4	4
Vector Capacity	2	1.5	1.5	2	2
Raster capacity	4	2	2	4	4
Interoperability	5	5	5	3.5	5
Performance	4	3	3.5	3.5	4
Map Generation	6	4.5	4.5	6	5
Documentation and Support	3	1.5	2	2.5	3
Total		**29.5**	**28**	**36.5**	**37**

of functionality and domain of use) and longevity of the software.

Different investigations make comparisons between various GIS. Ruiz (2016) analyzes QGIS, gvSIG and ArcGIS in terms of tools that they provide for the creation of vector symbology and labeling, existing compatibility for exporting and importing styles and symbologies, in addition, the capabilities for making map series are also examined automatically. The investigation is concluded by stating that ArcGIS and QGIS for the elaboration of vector symbology present great similarities, while gvSIG has great limitations in this aspect; the QGIS interface for the design of the different cartographic symbols is simpler and more intuitive for the user, presenting all the tools in the same window; but the capabilities of the GIS for the placement of the labels on a map still have a lot to improve, since a good labeling requires numerous decisions that the software at the time of the investigation is not capable of adopting; ArcGIS introduces an advanced type of labeling that, along with the utility of its annotation layers, makes label placement much easier for the user, well beyond the capabilities of the other two programs.

On the other hand, Olivo-Bermeo (2019) compares the GIS applied in environmental case studies, where the key comparison factor is the system license (free or commercial software). Several factors are analyzed for both groups such as layer management, application method, general configuration, interface, image treatment, among others. A weight is assigned to the determinant factors in the author's opinion that allow them to be compared. Table 3 shows the final result of the study carried out.

The investigation concludes by highlighting that commercial software presents greater reliability and profitability, based on the software evaluation parameters, presenting greater interoperability, map generation, functionality, capacity and analysis in terms of the characteristics of its tools. Although GIS must also be valued for its applicability and the functionalities that are required, since in certain environmental studies a GIS has better characteristics than others.

Using one GIS or another depends a lot on the needs of the user, the characteristics of what is wanted to be done and the budget available. It is necessary to analyze if the budget available and the use of paid software can be balanced. Several users place ArcGIS as the most complete GIS and the one with the most functionalities, but nevertheless QGIS has become in recent years a reliable free alternative that meets most of the community's requirements.

GIS Applications in Agriculture

Many challenges are adding pressure on today's agricultural supply chains including shrinking land size, increasing demand for natural resources and environmental concerns. Farming systems need a major transformation from traditional practices to precision farming or smart farming practices to overcome these challenges. GIS is one such technologies driving current methods towards precision agriculture (Sharma *et al.*, 2018). According to the United Nations Organization, the world population in July 2022 was 7.9 billion people. It is estimated that in 2030 it will be 8.5 and by 2100 11.2 billion people. This growth imposes the challenge for food production, coupled with the promotion of socioeconomic growth, the adoption of sustainable production systems and adaptation to climate change. Given the socio-environmental impact of agriculture, the World Food and Agriculture Organization recommends five principles to make it sustainable. They are: improving efficiency in the use of resources; carrying out direct activities to conserve, protect and improve natural resources; protecting and enhancing rural livelihoods, equity and social well-being; strengthening the resilience of people, communities and ecosystems and implementing responsible and effective public policies that ensure the sustainability of agriculture and food (Ocampo & Santa Catarina, 2018).

Today, the application of GIS has penetrated all aspects of society, involving all relevant spatial information fields, such as agriculture, forestry, water conservation, land, resources, and the environment. Specific applications include natural resource management, agricultural and commercial design, political and economic analysis, urban land planning, engineering design management, science, education, culture and physical training, technology national defense, financial transportation, public facilities and other fields (Zhang & Cao, 2019).

GIS plays a key role in today's agriculture. Its use enables, among other things, the classification, mapping and cartography of crops with georeferenced information. Also the identification of phenological stages of plants, irrigation monitoring and yield prediction. All this is based, fundamentally, on sources of information such as satellite images, aerial photogrammetry and harvest data from agricultural machinery (Pérez-García *et al.*, 2019).

According to Zhang and Cao (2019) some of the specific uses of GIS in agriculture are to carry out:

- Agricultural zoning surveys
- Crop yield estimation
- Precision Agriculture
- Surveys and vegetation cover accounting
- Forest management decision making plans
- Detection of forest fires

Monitoring market trends, improving yields and predicting the weather are among the many responsibilities required to reduce the risk of loss and increase the profitability of producing fields. Using geospatial analysis and predictive modeling, farmers have the ability to visualize their land, crops and management practices. Accessing spatial data has become an essential agricultural practice. Government agencies such as the US Department of Agriculture (USDA) and the European Union host websites that provide valuable information to help farmers in a better understanding of their land and making decisions that are more informed. This data can be accessed on the internet and used to create smart maps for better agricultural business practices (Reza & Mohammad, 2015).

In recent years, work in agricultural remote sensing has focused more on the characterization of the biophysical properties of plants. Remote sensing has been used for a long time in the monitoring and analysis of agricultural activities. Remote sensing of agricultural canopies has provided valuable information on various agronomic parameters. The advantage of remote sensing is its ability to provide repeatable information without destructive crop sampling, which can be used to provide valuable information for precision farming applications. Remote sensing offers an inexpensive alternative for data acquisition over large geographic areas (Palanisamy *et al.*, 2019).

In their work Budiharto et al. (2019) comment on the use of unmanned aerial vehicles (UAVs) in agriculture. They explain the boom in recent years in the use of drones for spraying fields, pest control, as well as mapping productive land. They indicate that the images of the terrain that can be obtained through satellites do not always have the necessary quality to detect certain anomalies in the crops or to detect their own crops; hence, drones play a fundamental role in this regard. They express that the information captured by the drones is stored and georeferenced to be displayed later through a GIS, being able to georeference each captured aspect for later analysis using, for example, Deep Learning techniques (Deep Learning)[*]. On the other hand, Sambrekar and Rajpurohit (2019) promote the use of Cloud Computing applied in agricultural processes[†]. They indicate that the information obtained from the fields makes it possible to determine marginal crops grown on fragmented land, quantify their effect on crop yields and detect crop stress due to nutrients and diseases. They indicate that the application of cloud computing techniques enables user access to the storage resource at anytime and anywhere through the Internet.

CONCLUSIONS

A GIS is a computer tool used to analyze geographic information. It is not a simple digitized map, nor a map container. It contains a spatial database and attributes or descriptive information about a map's features that can be used to create preferred maps. The fundamental advantage of GIS is the separation of spatial or geographic reference information and attribute or descriptive information of map features for data entry and database development and their linkage during analysis. Separating the two types of information makes it easier to enter spatial information (map) into computers in digitized form and to establish connectivity (topology) between the different stored map features (points, lines, and polygons). The feature attribute data is entered independently taking care to introduce an identification variable for each feature that is shared with the database space. For geographic analysis, spatial and attribute data is linked through this unique identifier variable common to both types of databases.

Initially, spatial data capture is done in spatial units and data capture instrument coordinates. In order to

*Fast-growing domain of machine learning, primarily for solving problems in computer vision. It is a class of machine learning algorithms that use a cascade of many layers of nonlinear processing.

†It is the use of a network of remote servers connected to the Internet to store, manage and process data, servers, databases, networks and software. Instead of relying on a physical installed service, it is possible to have access to a framework where software and hardware are virtually integrated.

translate map information into real-world information of locations, distances, and areas, these must be translated into real-world units through appropriate scale transformations and map projections.

Digitized maps and their associated feature attributes are the building blocks of GIS. Maps can be created and stored in different layers, each of which contains information about a feature. They can be overlaid on each other to obtain new maps (coverages) with new polygons that are homogeneous with respect to the attributes of the specified features of the maps that were used in the overlays. Overlay operations must be between maps with exact boundary settings. Exact fits are obtained between maps only if they are created in the same projection and scale. To make exact adjustments to map scale transformation and projection overlay operations, the appropriate map scale transformation and projection operations will be necessary before geographic analysis can be performed using overlay operations.

There are current GIS software with a large number of implemented functionalities that allow the proper handling of geographic data. It is always necessary to carry out a study when using a GIS which of the currently created implementations best suits the needs of the problem in question. Another important aspect to take into account is whether there is a need to use paid software or whether the current free software covers the needs.

GIS systems are expected to gain momentum in the coming years due to their ability to graphically represent geographic objects, thus demonstrating the spatial relationships between them easily and improving the functionality and ease of use of many applications. On the other hand, the evolution of GIS development tools facilitates the development of efficient GIS applications adapted to each application domain. The new lines of research described above will also provide GIS with greater functionality than current tools, mainly in certain application environments (cadastre, network management, navigation, among others).

The introduction of digital technologies improves the quality of farmland monitoring and the accuracy of criteria assessments of crop condition parameters and fertility levels, including the ability to locate and map soil degradation processes.

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The authors of this work declare no conflict of interests.
AUTHOR CONTRIBUTIONS: Conceptualization: G. Pérez, N. Machado. **Data curation:** G. Pérez, N. Machado. **Formal Analysis:** G. Pérez, N. Machado, M. E. Ruiz. **Software:** G. Pérez, N. Machado. **Supervision:** G. Pérez, N. Machado, M. E. Ruiz. **Validation:** G. Pérez, N. Machado, M. E. Ruiz, I. Sosa. **Visualization:** G. Pérez, N. Machado, I. Sosa. **Writing - original draft:** G. Pérez, N. Machado, M. E. Ruiz. **Writing - review&editing:** G. Pérez, N. Machado, M. E. Ruiz, I. Sosa.